1.6 SENSIBLE HEAT FLUX MEASUREMENTS USING A LARGE APERTURE SCINTILLOMETER OVER HETEROGENEOUS SURFACE

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1. INTRODUCTION

The issue of estimating areal average of the turbulent surface fluxes over large and heterogeneous surfaces has been addressed in the framework of different field experiments. It is therefore well accepted that the above objective cannot be fulfilled without deploying a network of several single point measurements of surface fluxes, i.e., eddy correlation stations for example. Beside some of the technical limitations related to the required horizontal homogeneity of the surface layer, these systems are very expensive and required well trained staff to maintain (DeBruin et al. 1995).

Several investigations have recently demonstrate the potential of using scintillometer to measure areally averaged sensible heat fluxes over path lengths which are similar to satellite pixel scale i.e., several kilometers (Kohsiek, 1987; De Bruin *et al.*, 1995; McAneney *et al.,* 1995; Lagouarde *et al.,* 1996; and Hartogensis, 1997). The idea behind the use of the scintillometer is based upon the consideration that the refractive index structure parameter measured directly by the scintillometer (C^2_n) can be related to the structure function parameter of temperature (C^2_T) which is used to derive sensible heat flux. The objective of this study is to use the scintillometer to estimate areally averaged sensible heat flux over sparse grass in the Mexican part of the San Pedro bassin. The scintillometer-based sensible heat flux over 3 different pathenghts (300, 600 and 900m) is compared to that obtained using an eddy correlation method.

2. BACKGROUND

A scintillometer is an instrument that measure the intensity fluctuations of a light beam after propagating through a turbulent medium. It is assumed that these intensity fluctuations are caused by inhomogenities in the refractive index, which are due to turbulent eddy motions along the scintillometer path. These eddy motions are generated by temperature and humidity fluctuations, and can be regarded as a collection of converging and diverging lenses focusing and defocusing the scintillometer beam. (McAneney et al., 1996). In the visible and infra-red region, and assuming that temperature and humidity fluctuations are perfectly correlated, the spatially averaged refractive index structure parameter measured directly by a Large Aperture Scintillometer (LAS) is related to temperature structure parameter as:

$$C_T^2 = C_n^2\left(\frac{T^2}{-0.78\cdot 10^{-6}P}\right)^2\left(1+\frac{0.03}{b}\right)^{-2} \quad (1)$$

where T is the air temperature (K) , P is the atmospheric pressure (P_a) and b is the Bowen ratio (see DeBruin et al., 1995 for more details). The Bowen ratio term in Eq. (1) is an humidity correction term. The study by De Wekker (1996) has shown that this term can be neglected whenever the Bowen ration is greater than 0.6, which is generally the case in arid and semi-arid areas. Since the sensible heat and momentum fluxes together determine atmospheric stability, which in turn influences turbulent transport, an iterative procedure is needed to calculate sensible heat flux from the scintillometer measurement (Lagouarde et al., 1996). We first define the dimensionless temperature scale θ* as :

$$q* = -H / r\ c_p\ u* \quad (2)$$

where r is the density of the air and c_p is the heat capacity at constant pressure, and u* is the friction velocity as :

$$u* = \frac{ku}{\ln\left(\frac{z-d}{z_0}\right) - y_m\left(\frac{z_0}{L_{mon}}\right)} \quad (3)$$

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where z is the measurement height , z_o is the roughness length and d is the displacement height and Υ_m is the integrated stability function, and L_{mon} is the Monin-Obukhov length defined as:

$$L_{mon} = \frac{Tu_*^2}{kgq_*^2} \tag{4}$$

Under unstable condition, Wyngaard *et al*. (1971) and DeBruin et al. (1995) found that the temperature structure parameter C_T^2 and Q^* are related as :

$$\frac{C_T^2(z-d)^{2/3}}{q_*^2} = 4.9\left(1 - 9\frac{z-d}{L_{mon}}\right)^{-2/3} \tag{5}$$

Sensible heat flux can then be derived using Eqs (1-5) and an iterative procedure.

3. EXPERIMENTAL

This study is a part the SALSA program (See Goodrich et al. , this issue). The objective of the investigation in the Mexican part of the Upper San Pedro basin is to better understand ecosystem function, and manage scarce natural resources by initiating the development and validation of a coupled SVAT and vegetation growth model for semi-arid regions that will assimilate remotely sensed data with several years of observed data.

Instrumentation were deployed during the summer of 1997 over sparse grass at the Zapata village situated about 10km East of Cananea (31,013° N, 110,09° W). The soil was mainly sandy loam. A Tower has been installed to measure conventional meteorological data (incoming radiation, net radiation, wind speed and direction , air temperature etc. etc.). Soil moisture was measured at both sites using Time Domain Reflectometry (TDR) sensors and Theta probes with sensitivity to 5 cm depth. Surface temperature was measured at two different view angles (0 and 45 degrees). Multidirectional ground based surface reflectance and the RED and NIR wavebands has been taken once a week during the entire growing season. Measurements of vegetation biomass, water content and leaf area index were made once a week. An eddy covariance system developed at the University of Edinburgh : Edisol (Moncrieff et al., 1997) has been used to measure turbulent surface fluxes. The system is made up of a three-axis sonic anemometer manufactured by Gill instrument (Solent A1012R) and an IR gas analyzer (LI-COR 6262 model) which is used in close path mode. The system is controlled by specially written software which calculates the surface fluxes of momentum , sensible and latent heat and carbon dioxide, from the output of the sonic and IR gas analyzer and displays them in real time. The software performs coordinate rotation on the raw wind speed data and allows for the delay introduced into CO2/H20 signal as a result of the time of the travel down the sampling tube.

The Large Aperture Scintllometer used in this study has been designed and built at the department of meteorology of the WAU. The electronics are according to Ochs and Wilson (1993). It has an aperture size of 0.15 m and the light source is a light emitting diode (LED: TIES-16A, Texas Instruments, Texas, USA) operating at a peak wavelength of 0.94 μm, which is placed at the focal point of a concave mirror. The reflected beam emitted by the transmitter diverges slightly at about ~0.002°. The irradiance distribution over the beam is completely uniform. The receiver also employs an identical mirror to focus light on a photo diode detector. To distinguish the light emitted by the LAS from ambient radiation it is excited by a 7 kHz square wave. Scintillations appear as amplitude modulations on the carrier wave. Receiver and emitter are both installed on tripods at a height of 2.6 m. For beam alignment, telescope rifle sights are mounted on both the receiver and emitter housings. The receiver electronics have been designed in such a way that after setting the path length , it gives an output voltage from which C^2_n follows using $C^2 n = 10^{(Vout-12)}$ with V_{out} is the output voltage of the scintillometer. 10 minute values of the scintillometer output (V_{out}) were stored on a data logger (Campbell Scientific Ltd, 21X). After downloading of these data, they were linearly averaged to 30-minute averages of V_{out}.

4. DATA ANALYSIS

The experiment took place in three phases. First, the LAS was installed over a transact of about 300m centered around the tower where the Solent was installed. The choice of 300m pathlength was meant to make sure that the LAS and the EC are integrating the same surface. Comparison between sensible heat flux values measured with the Solent (H_{Solent}) and that obtained by the scintillometer (H_{LAS}) from Day Of the Year (DOY) 206 to DOY 216 under unstable conditions is presented in Figure 1. This figure shows that the two measurements are in very good agreement especially with a range of sensible heat values up to 450 Wm^{-2}. A linear regression forced to the origin yields H_{LAS}=0.97 H_{Solent} , with a correlation coefficient R^2= 0.90.

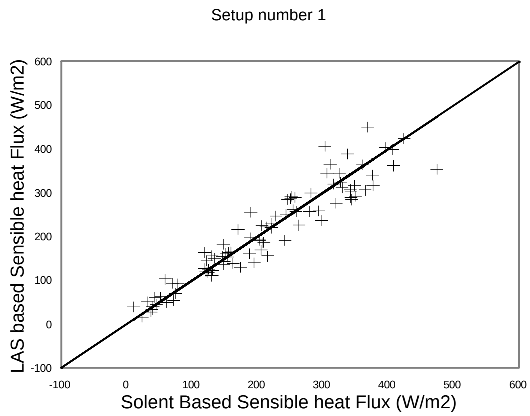

Figure 1: Comparison between sensible heat flux measured by the Solent and that measured by the scintillometer at a pathlength of 300m

During the second phase, the receiver and the transmitter were moved 150m in the opposite direction, which make the pathlength of about 600m. Figure 2, presents the same comparison as in Figure 1 for data taken under unstable condition from DOY 240 to DOY 250. It is seen that although the agreement is still good, the scatter is larger than in Figure 1, the correlation coefficient drops to 0.80.

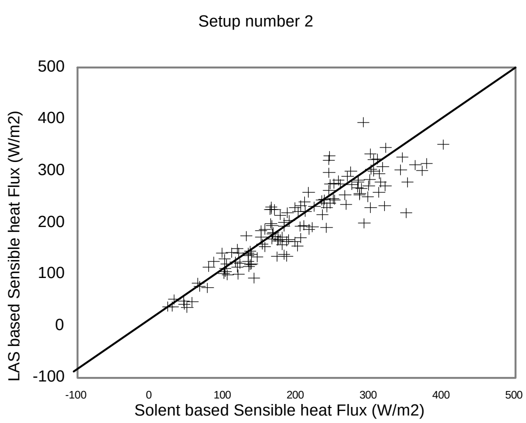

Figure 2: Comparison between sensible heat flux measured by the Solent and that measured by the scintillometer at a pathlength of 600m

During the third phase, the receiver and the transmitter were moved so that the pathlength was about 900 m. In Figure 3, the path-averaged values of sensible heat flux obtained by the LAS from DOY 258 to DOY 261 is plotted versus the corresponding values measured with the Solent.

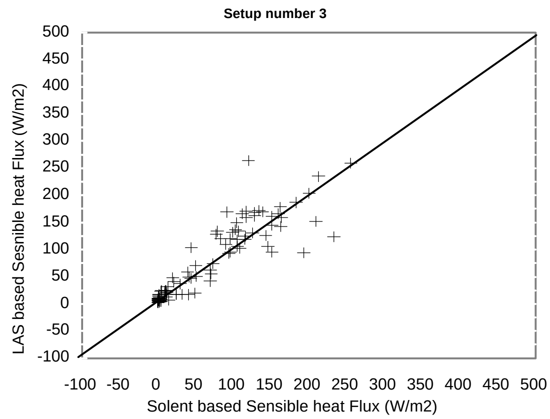

Figure 3: Comparison between sensible heat flux measured by the Solent and that measured by the scintillometer at a pathlength of 900m.

It can be seen here that scatter between the two measurements is getting larger, the correlation coefficient drops to 0.75. It is therefore clear that the scatter between the LAS and the Solent measurements increases when difference between the Solent footprint and the LAS pathlength increases. To emphasize this point, we present in Figure 4 the spatial variation of a vegetation index (MSAVI, Qi et al., 1994) derived from surface reflectance measurements using a field radiometer (Exotech) along the pathlength. The MSAVI value varies from 0.15 to 0.30 along the transact.

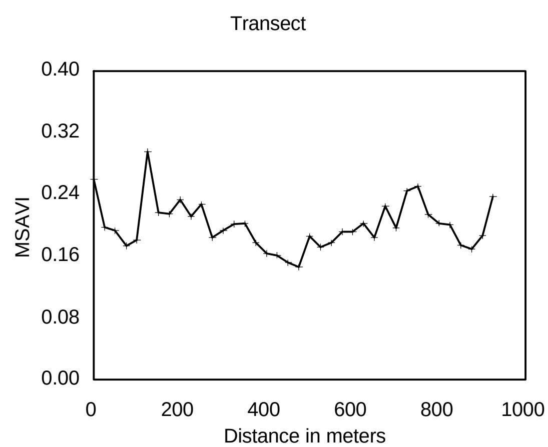

Figure 4: Spatial variation of MSAVI along the scintillometer pathlength.

These variations of MSAVI values along the transact which can be associated to variation of surface albedo and temperature and therefore to sensible heat flux. This rises the issue of the reliability of point based measurements of surface fluxes to validate large scale models even when the surface looks homogeneous.

5. CONCLUDING REMARKS

Several successful studies have been carried to investigate the feasibility of estimating sensible heat flux using the scintillometer (Kohsiek 1985; Green et al., 1994; De Bruin et al. 1995; McAneney et al. 1995, Lagouarde et al., 1996). This study confirms the results reported elsewhere and stressed out the problem of the non-representativeness of point measurements even over a quasi-homogeneous surfaces.

The LAS has several major advantages over more traditional methods, such as eddy correlation, for measuring sensible heat flux: a) it gives statistically more reliable data; b) it is not sensitive to flow distortions near the instrument; c) it is relatively cheap and easy to operate. Additionally, point based estimation of surface fluxes which are based on Monin-Obukhov similarity theory that requires horizontal homogeneity which is not always met in real world situation. The scintillometer can provides areally averaged values of sensible heat flux over heterogeneous surfaces by using the concept of blending height . This concept assumes that on a certain height above the surface, the differences in surface properties can be averaged out so that the similarity theory can be applied.

5. ACKNOWLEDGMENT

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